Charged Particle Ratio Fluctuation as a Signal for QGP*

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We show that the event-by-event fluctuations of the ratio of the positively charged and the negatively charged particles provides a signal of quark-gluon plasma. The fact that quarks carry fractional charges is ultimately responsible for this distinct signal.

The advantage of considering ratio fluctuations is that they do not depend on the ever present volume fluctuation in heavy ion collisions. In case of the fluctuations of the ratio

$$R = \frac{N_+}{N_-} \tag{1}$$

one can show that

$$D \equiv \langle N_{\rm ch} \rangle \left\langle \delta R^2 \right\rangle = 4 \langle N_{\rm ch} \rangle \left\langle \delta F^2 \right\rangle = 4 \frac{\langle \delta Q^2 \rangle}{\langle N_{\rm ch} \rangle} \tag{2}$$

where Q is the observed net charge. Therefore D measures the charge fluctuations per charged particle or, since the number of charged particles is related to the entropy of the system, the charge fluctuation per degree of freedom. This is obviously smaller in a Quark-Gluon-Plasma (QGP) as compared to a pion gas. In a pion gas $N_{\rm ch} = N_{\pi^+} + N_{\pi^-}$ and

$$\delta Q = \delta N_{\pi^+} - \delta N_{\pi^-} \tag{3}$$

Using thermal distributions and disregarding correlations, we get

$$\left\langle \delta Q^2 \right\rangle = \left\langle \delta N_+^2 \right\rangle + \left\langle \delta N_-^2 \right\rangle = \langle N_{\rm ch} \rangle \tag{4}$$

where we have ignored small corrections due to quantum statistics. Consequently

$$D = 4 \tag{5}$$

for a pion gas.

In a QGP on the other hand

$$\delta Q = Q_u \, \delta \left(N_u - N_{\bar{u}} \right) + Q_d \, \delta \left(N_d - N_{\bar{d}} \right) \tag{6}$$

where Q_q is the charges of the quarks and N_q is the number of quarks. Thermal distributions and no correlations yield

$$\left\langle \delta Q^2 \right\rangle = Q_u^2 \langle N_u \rangle + Q_d^2 \langle N_d \rangle \tag{7}$$

where N_q denotes the number of quarks *and* antiquarks.

Relating the final charged particle multiplicity $N_{\rm ch}$ to the number of primordial quarks and gluons is not as simple. To make an estimate, we assume that the entropy is conserved [1] and that all the particles involved are massless, in thermal equilibrium and non-interacting. This leads to

$$N_{\rm ch} = \frac{2}{3} \left(N_g + 1.2 N_u + 1.2 N_d \right) \tag{8}$$

with the result

$$D \simeq \frac{3}{4} \tag{9}$$

for a QGP, a factor of 5 smaller than the pion gas.

Using present lattice-QCD results for the charge fluctuations and entropy bring the value up to $D \simeq 1$ for the QGP. Taking into account resonances for the hadronic phase [2] bring the value of the pion gas down reduces to $D = 3$, still a factor of three difference which should provide a unique signature for the QGP.

[1] J. D. Bjorken, Phys. Rev. **D27**, 140 (1983).
[2] S. Jeon and V. Koch, Phys. Rev. Lett **83**, (1999) 5435.

* LBNL-45462, Phys. Rev. Lett. **85** (2000) 2076.